RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.:	**433-8363**
SRP Section:	**19 – Probabilistic Risk Assessment and Severe Accident Evaluation Section: 19**
Application Section:	**19**
Date of RAI Issue:	**03/08/2016**

Question No. 19-70

10 CFR 50.44(c)(5) and SECY-93-087 require a deterministic analysis that demonstrates containment structural integrity under internal pressure loads. Regulatory Guide 1.216, Regulatory Position 3 discusses the methods acceptable to the staff to address the Commission's performance goal related to the prevention and mitigation of severe accidents. The use of the Factored Load Category (FLC) for concrete containments is acceptable to demonstrate the deterministic performance goal for the first 24 hours.

APR1400 design control document (DCD) Tier 2, Section 19.2.4, "Containment Performance Capability," does not provide a description of the finite element models of the containment. The staff reviewed the information contained in the DCD, and in supporting calculations 1-316-C304-006 "Containment Building Capacity Evaluation on Severe Accident (Global) and 1-316-C304-007 "Containment Building Capacity Evaluation on Severe Accident (Local)". The staff identified information that needs to be clarified and explained in the DCD to complete its evaluation. This information includes modeling details, description of computer codes, material properties and material modeling, loading and loading sequences, failure modes, and interpretation or results. The staff requests the applicant provide reference to the Severe Accident Report in the appropriate section of the DCD. In accordance with Regulatory Position 3 of RG 1.216, the applicant is requested to address the following at a level of detail consistent with 10 CFR 50.47 and include this information in the DCD:

1. A description of the global and local nonlinear finite element models. Include a description of computer codes. The description should discuss how the large penetrations were treated in the models. The discussion should also include the treatment of smaller penetrations and penetration closure components.

2. The accident temperature associated with the severe accidents conditions. The staff requests the applicant provide a basis for assuming the accident temperature. Additionally, provide an explanation of how accident temperatures were considered in

selecting the material properties in the analysis, specifically for concrete strength. Calculation 1-316-C304-006 describes the effects of temperatures on the material properties for concrete, steel reinforcement, pre-stressing tendons, and the steel liner that should be included in the DCD.

3. A description of the material modeling for the concrete containment in the DCD. These properties are currently described in calculation 1-316-C304-006 and include the stress-strain relationship used for steel corresponding to the accident temperature, the stress-strain relationship used for concrete corresponding to the accident temperature, and any other material properties important to the model.

4. An adequate technical justification for all simplifications and the applicability to the particular containment design and loading condition. Simplifications include assumptions made based upon the use of test results. The staff notes that test results are presented in Appendix E of the Severe Accident Report, and requests that these be incorporated into the DCD. As an example, address the appropriateness of a static analysis and whether dynamic response effects are important.

5. A description of the analysis results.

Response

1. The three-dimensional finite element (FE) model for safety evaluation on severe accident is developed based on the design results (rebar arrangement) from structural analysis of the concrete containment. The FE code ABAQUS is used for the nonlinear analysis of the containment structure. The full FE model includes the entire prestressed concrete containment structure which consists of the concrete wall and dome, liner plate, rebars, and tendons. The solid and shell elements are used for concrete and liner plate, respectively, and the rebars and tendons were modeled as truss elements. In addition, the large, operating-type penetrations such as equipment hatch, personnel airlock, and main steam penetration are considered in the full FE model, but the electrical penetration assemblies and valve penetrations were excluded. With regard to the nonlinear finite element model, it will be reflected in DCD section 19.2.4.2.2 as shown in the Attachment.

2. As addressed in Calculation note “Containment Performance Analysis”, 1-035-N389-501, Rev.04, the accident temperature during the severe accident in viewpoint of Position 3 of RG 1.216 is determined by the following process:

   - Selection of more likely accident sequences: Based on the core damage frequency ranking from PRA Level 1 study, the top ten sequences are selected. Also a number of typical sequences which are important in deterministic approach are added in the calculation matrix, as listed in Table A-2, page 239 of 1-035-N389-501, Rev. 4.

   - Evaluation of the plant response by using MAAP code: For the selected sequences the plant response are evaluated by using MAAP code. The pressure and temperature transient are determined in each case.

- Decision of accident temperature: Based on the plant response, the temperature profile is decided such that it can envelop the selected sequences. Table 4-2 in the calculation note indicates that the highest pressure of 112 psia is predicted in case of Large break LOCA (No. 8 in the table), while the temperature of the containment wall of 332 ºF is slightly lower than the highest value of 334 ºF. Consequently the constant accident temperature of 350 ºF, which can bound the transient response of LLOCA as well as the rest set of the sequences, is employed, conservatively.

  The maximum temperature during a severe accident is 350 ºF and the degradation of material properties at this temperature is conservatively applied thru all analysis phases. The material degradation corresponding to the temperature is based on NUREC/CR-6906. In NUREC/CR-6906, the strength ratio of concrete and steel strength is as follows.

  For concrete strength ratio, $S_{Rc} = \exp -(T/632)^{1.8}$ where T is in degrees ºC.

  For steel yield strength ratio, $S_{Rs} = \exp -((T-300)/300)^{1.9}$ where T is in degrees ºC. If T is less than 340 ºC, $S_{Rs} = 1.0$

  Based on the NUREC/CR-6906, the compressive strength of concrete is 5,400 psi and 4,500 psi at 350 ºF for containment external wall and basemat, respectively. For reference, the design compressive strength of concrete is 6,000 psi and 5,000 psi for containment external wall and basemat, respectively. In addition, for the reinforcing steel and prestressing tendon, the yield strength ratio is 1.0 because the severe accident temperature is less than 340 ºC. The material degradation of liner steel (SA-516 Gr. 60) is based on the ASME Section II-D, the yield strength and tensile strength of liner steel are 27.9 ksi and 60 ksi at 350 ºF, respectively. For reference, the design yield strength and tensile strength of liner steel are 32 ksi and 60 ksi, respectively. With regard to the material degradation corresponding to severe accident temperature, it will be reflected in DCD section 19.2.4.2.2 as shown in the Attachment.

3. Material nonlinear models for steel and concrete are constructed on the basis of the design code and a few references. For simulating the cracking behavior of concrete, the smeared crack model is adopted. The steel is assumed to be a linear elasto-plastic model. The stress-strain curves for the reinforcing steel and tendons are based on the ASME code-specified minimum yield strengths. An elastic-plastic and a piece-wise linear stress-strain relationship above yield stress is used for the reinforcing steel and tendons. As mention in Q.19-70 (2), the degradation of concrete and steel material properties corresponding to the maximum temperature during severe accident is conservatively applied thru all analysis phases. With regard to the material nonlinear models, it will be reflected in DCD section 19.2.4.2.2 as shown in the Attachment.

4. The sequences analyzed covered the most likely severe accident initiators for APR1400. The top ten sequences from the Level 1 PRA study as well as the representative deterministic sequences are covered. Dominant contribution of containment pressurization in terms of Regulatory Position 3 is the generation of

massive steam and non-condensable gases during the severe accident. These gas and steam production phenomenon increase the containment pressure gradually as presented in Figure 19.2.3-21 of the DCD. Therefore static analysis against the severe accident load is applicable to the containment response. DCD section 19.2.4.2.2 will be revised as shown in the Attachment.

5. In all severe accident scenarios, the liner plate does not reach the limit strain of KEPIC SNB-3720 which is same to ASME CC-3720. In addition, the crack penetration of concrete of containment does not occur and the rebar and tendon keep elastic status. With regard to the analysis results, it will be reflected in DCD section 19.2.4.2.2 as shown in the Attachment.

Impact on DCD

DCD section 19.2.4.2.2 will be revised, as indicated in the Attachment.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environmental Report.

the complete reaction of 100 percent of the active fuel cladding with steam. Also, the hydrogen mitigation features are assumed to be unavailable. The hydrogen was then assumed to be burned completely with no heat transfer to heat sinks in the containment with initial containment atmospheric pressure at the highest value possible that would still allow for hydrogen to burn. The maximum pressure load on the containment structure is evaluated to be 7.0 kg/cm^2 (99.8 psia) under the AICC condition. Considering the safety margin of APR1400 containment, for the FLC, the pressure resulting from 100 percent metal water reaction of fuel cladding and resulting from uncontrolled hydrogen burning is determined as 8.7 kg/cm^2 (123.7 psia).

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19.2.4.2.2 Containment Pressurization Results

Figure 19.2.3-21 shows the containment pressure response for a large-break LOCA that results in the highest containment pressure at 24 hours following the onset of core damage. For this scenario, the containment pressure does not reach 8.7 kg/cm^2 (123.7 psia) for 24 hours after the onset of core damage.

19.2.4.2.3 Emergency Containment Spray Backup System Performance

For a provision against a beyond-design-basis accident where either two SC pumps and two CS pumps or the IRWST is unavailable, the ECSBS is provided as an alternative to the CSS.

The ECSBS is designed to protect the containment integrity against overpressure and prevent the uncontrollable release of radioactive materials into the environment. The emergency containment spray flow path is from external water sources (the reactor makeup water tank, demineralized water storage tank, fresh water tank, or the raw water tank), through the fire protection system line via the diesel-driven fire pump, to the ECSBS line emergency connection located at ground level near the auxiliary building.

The ECSBS flow rate provides sufficient heat removal to prevent containment pressure from exceeding 8.7 kg/cm^2 (123.7 psia). In order to evaluate the performance of ECSBS, analysis is performed using the MAAP code.

Sequences are analyzed assuming that ECSBS operation began 24 hours after the onset of core damage. Figure 19.2.3-21 shows the containment pressure response following the

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Security-Related Information - Withhold Under 10 CFR 2.390

Regarding the Regulatory Guide 1.216, Regulatory Position 3, accident sequences to be analyzed are selected in combination of top ten dominant sequences from Level 1 PRA study and deterministic sequences. In accordance with the design of APR1400, Cavity Flooding System (CFS) and ECSBS were included in the sequences. Among the selected sequences a large-break LOCA resulted in the highest pressure in containment at 24 hours following the onset of core damage. The peak pressure and temperature is [ ] and [ ], respectively, as shown in Figure 19.2.3-21. The massive generation of the steam and non-condensable gases during the severe accident has dominant contribution on the gradual and increment of pressure and temperature. The bounding pressure and temperature profile is then employed in the static finite element study of the containment.

Under these conditions, the loadings should not produce strains in the containment liner plate in excess of the limits established in ASME Code, Section III, Division 2, Subarticle CC-3720. Allowable strains for factored loads considering membrane only are 0.005 in compression and 0.003 in tension. Allowable strains for factored loads considering membrane and bending are 0.014 in compression and 0.010 in tension.

The three-dimensional finite element (FE) model for safety evaluation under severe accident is constructed based on the design results (rebar arrangements) of the structure. The FE code ABAQUS is used for the nonlinear analysis of the containment structure. The full FE model includes the entire prestressed concrete containment structure which consists of the concrete wall and dome, liner plate, rebars, and tendons. The solid and shell elements are used for concrete and liner plate, respectively, and the rebars and tendons were modeled as truss elements. In addition, the large, operating-type penetrations such as equipment hatch, personnel airlock, and main steam penetration are considered in the full FE model. Material nonlinear models for steel and concrete are constructed on the basis of the design code and a few references. For simulating the cracking behavior of concrete, the smeared crack model is adopted and tension stiffening effect is also taken into consideration. The stress-strain curves for the reinforcing steel and tendons are based on the ASME code-specified minimum yield strengths. An elastic-plastic and a piece-wise linear stress-strain relationship above yield stress is used for the reinforcing steel and tendons. The maximum temperature during severe accident is [ ] and the degradation of material properties at this temperature is conservatively applied thru all of analysis phases.

Based on the results of the analyses, the crack penetration of concrete of containment does not occur, and all of the tendons and rebars are still in the elastic stage. At the LLOCA scenario, the maximum strain of liner plate considering at the cylindrical wall base, mid-height wall, and penetration regions is [ ] and [ ] for compression and tension, respectively. At the LOFW scenario, the maximum strain of liner plate considering at the cylindrical wall base, mid-height wall, and penetration regions is [ ] and [ ] for compression and tension, respectively. At the SBO scenario, the maximum strain of liner plate considering at the cylindrical wall base, mid-height wall, and penetration regions is [ ] and [ ] for compression and tension, respectively. In all severe accident scenarios, the liner plate does not reach the allowable limit strain values of membrane only load and combined membrane and bending load.

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Question No. 19-72

10 CFR 50.44(c)(5) and SECY-93-087 require a deterministic analysis that demonstrates containment structural integrity under internal pressure loads. Regulatory Guide 1.216, Regulatory Position 3, discusses the methods acceptable to the staff to address the Commission's performance goals related to the prevention and mitigation of severe accidents. The use of the Factored Load Category (FLC) for concrete containments is acceptable to demonstrate the deterministic performance goal for the first 24 hours.

In Section 19.2.4.2.1, the applicant states: "Considering the safety margin of APR1400 containment, for the FLC, the pressure resulting from 100 percent metal water reaction of fuel cladding and resulting from uncontrolled hydrogen burning is determines as 8.7 kg/cm2 (123.7 psia)". Please clarify whether this pressure corresponds to the pressure at which the liner strain equals the limits established by the FLC requirements of ASME Code, Section III, Division 2, Subarticle CC-3720. Otherwise, please clarify how the 8.7 kg/cm2 (123.7 psia) pressure value was determined. Clarify what "considering the safety margin" means.

Response

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Impact on DCD

There is no impact on DCD.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environmental Report.

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Question No. 19-81

10 CFR 50.44(c)(5) and SECY-93-087 require a deterministic analysis that demonstrates containment structural integrity under internal pressure loads. Regulatory Guide 1.216, Regulatory Position 3, discusses the methods acceptable to the staff to address the Commission's containment performance goal for the period following the initial 24 hours after the onset of core damage.

The staff noted inconsistencies in the plots of maximum pressures for the large-break loss-of coolant accident (LBLOCA) scenarios between Figure 19.2.3-21 and the Containment Building Capacity Evaluation on Severe Accident (Global) Calculation #1-316-C304-006. The staff requests that the applicant clarify the differences between the two scenarios and explain why the accident scenarios considered are actually those with the most significant pressure loading histories.

Response

Regarding Regulatory Position 3, Response to Chapter 19 RAI 433-8363 Question 19-71 item 1 addresses a basis for the accident selection and the calculated bounding pressure. Briefly it can be classified into the following steps.

- Selection of more likely accident sequences: Based on the core damage frequency ranking from PRA Level 1 study, the top ten sequences are selected. Also a number of typical sequences which are important in deterministic approach are added in the calculation matrix, as listed in Table A-2, page 239 of Calculation note "Containment Performance Analysis," 1-035-N389-501, Rev. 4.

- Evaluation of the plant response by using MAAP code: For the selected sequences the plant response are evaluated by using MAAP code. The pressure and temperature transient are determined in each case.

- Decision of bounding pressure load: Based on the plant response, the pressure profile is selected such that it can envelop the selected sequences. Table 4-2 in Calculation note indicates that the highest pressure of 112 psia is predicted in case of Large break LOCA (No. 8 in the table). Consequently the pressure curve obtained on the LBLOCA sequence, as shown in Figure 19.2.3-21 in DCD, is then applied to the containment structural strain analysis.

The revised Calculation notes (1-316-C304-006 Rev.3 and 1-316-C304-007 Rev.3) clearly indicates that the bounding pressure selected from the more likely severe accident sequences are employed as the input load profile.

Impact on DCD

There is no impact on DCD.

Impact on PRA

There is no impact on PRA.

Impact on Technical Specifications

There is no impact on Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environmental Report.

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Question No. 19-84

10 CFR 50.44(c)(5) and SECY-93-087 require a deterministic analysis that demonstrates containment structural integrity under internal pressure loads. Regulatory Guide 1.216, Regulatory Position 3 discusses the methods acceptable to the staff to address the Commission's performance goal related to the prevention and mitigation of severe accidents. This includes guidance on the development of global and local finite element models of the containment.

a. As per RG 1.216, ASME, Section III. Division 1, Subsection NE, covers metal portions of concrete containments that are not backed by concrete. Therefore, such components need to be shown to meet the Service Level C requirements in Subsection NE-3220. The staff review of the Containment Building Capacity Evaluation on Severe Accident (Local) did not find sufficient information to confirm that the covers for the large penetrations analyzed meet the Service Level C requirements in Subsection NE-3220. The staff requests the applicant demonstrate that the covers for the large penetrations meet the Service Level C requirements in Subsection NE-3220 of the ASME code.

b. As per RG 1.216, the evaluation should consider the potential for containment leakage at pressure levels below the calculated structural capacity. The applicant should perform analyses to demonstrate that leakage from containment components, such as penetrations, bolted connections, seals, hatches, or bellows, is sufficiently small for the calculated pressure and temperature capacity conditions. Otherwise, the pressure capacity should be based on a defined total leakage limit from these components. The staff requests the applicant explain how the consideration of containment leakage was accounted for when modeling local regions of containment.

Response

a. The equipment hatch and personnel airlocks are vendor designed components. The COL applicant is to demonstrate that the covers for the large penetrations such as equipment hatch and personnel airlocks meet the Service Level C requirements in Subsection NE-3220 of the ASME code.

b. The COL applicant also will explain how the consideration of containment leakage is accounted for when modeling local regions of containment.

COL 19.2(3) The COL applicant will demonstrate that the covers for large penetrations such as equipment hatch and personnel airlocks meet the Service Level C requirements in Subsection NE-3220 of the ASME code and explain how the consideration of containment leakage is accounted for when modeling local regions of containment.

Impact on DCD

DCD Tier 2, Subsection 19.2.3.3.7.4.8 and 19.2.7 will be revised as shown in the Attachment associated with this response.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environmental Report.

Thermally limiting components in the equipment hatch and PAL are EPDM O-rings, compression seals, and gaskets. In the Sandia/CBI Personnel Airlock Testing (Reference 36), an actual full-scale airlock assembly was subjected to environmental conditions corresponding to severe accident events. In particular, Test 2C consisted of three thermal and pressure cycles. In the second cycle, air temperature was raised to 700 K (800 °F), and the pressure was increased to 21.09 kg/cm^2 (300 psig). There was no measurable leakage of the inner door seal. In the tests, it was determined that the temperature at which the material deteriorates is approximately 600 K (620 °F). Indeed, the peak temperature recorded on the door surface when the seal failed during the third cycle was 633 K (680 °F). The Test 2C results demonstrated that the EPDM seal material survives the ambient temperature over 24 hours. Hence, the seal and gaskets in the equipment hatch and PALs are expected to maintain their integrity during severe accidents.

The COL applicant will demonstrate that the covers for the large penetrations such as equipment hatch and personnel airlocks meet the Service Level C requirements in Subsection NE-3220 of the ASME code and explain how the consideration of containment leakage is accounted for when modeling local regions of containment (COL 19.2(3)).

19.2.3.3.7.4.9 Electrical Penetration Assembly (EPA)

The EPAs are installed on the containment pressure boundary and are sealed with double O-rings. The EPAs are located in the annular compartment at various elevations above the operating deck. The thermally limiting components in EPAs are Viton O-rings, polysulfone module conductor sealant, and polyimide film conductor insulation. A Conax EPA was tested under severe accident conditions by Sandia National Laboratories (Reference 37). The EPA was a lower voltage penetration assembly with a typical cable mix for power, control, and instrumentation functions. The EPA was first irradiated and then thermally aged. Then, the EPA was exposed to steam at 9.49 kg/cm^2 (135 psia) and 644 K (700 °F) for 8 days. The temperature in the test chamber reached the maximum value, 644 K (700 °F), about 45 minutes into the test. Temperature in the junction box reached the steady-state temperature of about 561 K (550 °F) about four hours into the test. Temperature on the header plate reached the steady-state temperature of about 444 K (340 °F) about four hours into the test. The leak integrity of the Conax EPA was maintained during the entire 10-day period of the severe accident test. The test condition exceeds the long-term severe accident condition. Hence, the seal in the EPA is expected to maintain its integrity during severe accidents.

19.2.6.7 Conclusions

The analyses described in the previous sections analyzed conceptual alternatives for mitigating severe accident impacts in the APR1400 design. Preliminary screening eliminated all SAMDA candidates from further consideration, based on inapplicability to the design, design features that have already been incorporated into the design, inapplicability to a design certification stage, or extremely high cost of the alternatives considered.

The analysis using a 7% discount rate showed that no design changes to reduce risk associated with contributors to plant risk would be cost-beneficial to implement. A second baseline maximum benefit calculation using a 3% discount rate showed only minor variations in the calculated benefits. Therefore, it is concluded that no design changes would provide a positive cost-benefit if included in the APR1400 design.

19.2.7 Combined License Information

COL 19.2(1) The COL applicant is to perform and submit site-specific equipment survivability assessment in accordance with 10 CFR 50.34(f) and 10 CFR 50.44.

COL 19.2(2) The COL applicant is to develop and submit an accident management plan.

COL 19.2(3) The COL applicant will demonstrate that the covers for the large penetrations such as equipment hatch and personnel airlocks meet the Service Level C requirements in Subsection NE-3220 of the ASME code and explain how the consideration of containment leakage is accounted for when modeling local regions of containment.

19.2.8 References

1. SECY-93-087, "Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-Water Reactor (ALWR) Designs," U.S. Nuclear Regulatory Commission, April 1993.

2. 10 CFR Part 100, "Reactor Site Criteria," U.S. Nuclear Regulatory Commission.

3. 10 CFR Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants," Title 10, Code of Federal Regulations, ,U.S. Nuclear Regulatory Commission.

4. 10 CFR 50.34, "Contents of Applications; Technical Information," U.S. Nuclear Regulatory Commission.